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ABSTRACT

This paper describes the performance of a 56,000-m² office building emphasizing the use of daylighting for ambient illumination. Natural light serves 3,000 employees in open-plan offices through the building's five floors. The architectural scheme includes ceilings that slope from 4.25 m (perimeter) to 2.75 m (center), 3.5-m-deep light shelves at the exterior walls, and a central atrium providing light to interior spaces. An electric lighting system supplements available daylight, when necessary, using fluorescent fixtures with continuously dimming ballasts controlled by photocells. Monitoring during a one-year period has confirmed that the daylighting elements of the building provide ambient illumination in a pattern predicted by the design studies. Between 8AM and 6PM on an average summer day, the building's southern half can potentially maintain the target illuminance of 350 lux with an electric lighting load of 44% full power. The northern half of the building would require less electrical lighting at 31% of full power. However, actual measured electrical power consumption for ambient lighting is higher at 75% of full power for the south side and 50% of full power for the north side. The daylighting component of interior illuminance peaks at seven times the target level for ambient light. Proper design and tuning of the electric light control system was determined essential for the realization of projected savings in electric power consumption.

INTRODUCTION

The Windows and Daylighting Group of Lawrence Berkeley Laboratory recently completed an assessment of the potential of daylight as a commercial-sector energy-conserving strategy.¹ The study concluded that "performance data for daylighted buildings is virtually nonexistent. A review of over 40 'daylighted' buildings described in the architectural and engineering press provided virtually no useful data on the magnitude of daylight savings. These data are necessary, not only to validate computer models that provide guidance to designers, but also to convince hardnosed decision makers that these approaches are viable and cost effective."

This paper describes a post-occupancy study providing monitored performance data for an innovative daylighted office structure in the San Francisco Bay Area. The structure represents a major advancement in daylighting use by a large U.S. corporation that seeks reduced energy consumption, lower peak demand, and improved employee productivity. The 56,000-m² office is occupied by 3,000 technical personnel in open-plan offices. The building, diagrammed in Figure 1, is a design strongly driven by daylighting. The building plan is elongated on an east-west axis producing major fenestration surfaces facing roughly north and south (the building is actually turned approximately 25 degrees west of south). Building functions lacking a strong relationship to daylighting (computer facilities, conference rooms, rest rooms, copy rooms, etc.) are gathered into opaque core groups placed on the east and west ends of the building. A central atrium was introduced to provide light, visual relief, circulation, and drama to the building's large interior zones. The building has a high floor-to-floor dimension (5.5 meters) to increase the depth of daylight penetration from exterior and atrium openings, with a sloped ceiling to intercept and reflect illuminance from the light shelves. Large light shelves are located along both north and south exterior walls. The horizontal interior light shelves are about 2.3 meters above the floor and extend inward 3.75 meters from the exterior glazing. The south side of the building has an additional exterior light shelf with a reflective white upper surface. To further reduce glare and winter solar gain, the glazing below the light shelf has a relatively low transmittance (17% on the south side and 41% on the north). Ambient illumination for circulation and casual tasks is provided by daylighting whenever possible and supplemented by indirect fluorescent ceiling fixtures. A photosensor provides the signal to control each circuit's continuous-dimming system. A separate computer-based control system turns the lights off at scheduled periods of low occupancy. Task lighting is provided by individually controlled fixtures built into each workstation.

We have conducted a field study of lighting and fenestration-system performance in this building.² The study's primary objectives are to establish a profile of daylighting and electrical lighting patterns within this new structure and to analyze the relationships between daylighting availability, interior illuminance, and electrical lighting power consumption. This paper reports the first findings of our project.

THE STUDY

The study of an existing building poses some interesting technical challenges. Instrumentation must be installed with minimal disturbance to the building occupants and with an orderly routing of sensor wiring. Our measurement strategy applied four independent battery-operated dataloggers to collect readings at 28 sensor locations. The use of Campbell Scientific Model CR-21 dataloggers allowed short analog sensor wiring runs and flexibility in sensor placement. Data was stored on digital cassettes and downloaded in the field to a portable microcomputer for off-site evaluation. Characterization of interior lighting patterns was based on LiCor 210S photometric sensors placed across sectional profiles in representative daylight zones of the building. Ambient illuminance measurements in a horizontal plane were collected at partition height, 1.8 m above the floor. Additional photometric sensors were located in the volume above the interior light shelves. Lighting power circuits for corresponding light fixtures were monitored by Ohio Semitronic PC5-59C watt transducers in the local electrical closet.

Data were collected from February 1985 until January 1986. During this time detailed measurements were made in three different zones of the building. Preliminary site visits with hand-held instrumentation established the third floor as a representative floor. Data were collected for three-week periods across a horizontal section of the south side of the third floor, then across a similar profile of the north side and finally in a vertical section across all floors along the atrium edge. Most of the data represents summer conditions. Detailed measurements for the south side were repeated for equinox and winter conditions.

BUILDING PERFORMANCE

Monitored performance data indicate a number of interesting trends in the daylighting patterns of the building. Typical data for interior illuminance under summer clear sky conditions are shown in Figure 2. The south side of the structure, with exterior light shelves and low-transmittance glass, is strongly influenced by beam sunlight. Interior illuminance is low during the morning hours but rises quickly as direct sunlight strikes the exterior light shelf. Peak interior readings 4 meters from the exterior wall exceed 1200 lux, almost 4 times the target of 350 lux. In order to prevent glare in the immediate vicinity of the window, a combination of low-transmission glazing and shading from the exterior light shelf was used, so the area immediately below the light shelf does not receive enough natural light to exceed 350 lux. Thus there are lower levels of natural light in the zone closest to the window than in the interior zones. Illuminance levels 13 meters from the exterior wall peak at approximately 250 lux. Though this does not provide 100% of ambient illuminance, it does reduce the electric lighting load significantly.

The north side of the building has an entirely different daylighting character. The north sky provides diffuse light to this zone, which has higher-transmittance glass and no exterior reflector. Interior illuminance here does not reach the high levels of the south side, peaking at 600 lux. The interior light levels, however, consistently exceed the 350-lux target and therefore provides substantial dimming potential. The area immediately beneath the light shelf has higher daylight levels than its south-side counterpart because of the higher transmittance of the view glazing. Like the south side, the

regions near the center of the north zone do not reach target light levels.

Illuminance levels near the atrium edge on both sides are quite high and fall rapidly nearer the building's interior. A 6000-lux reading at the atrium edge becomes 700 lux at 3.5 meters from the edge and 400 lux at 5.5 meters.

Observations and manual testing of the fluorescent ballast dimming system at night indicated that it was operating within manufacturer's specifications, but was not reaching its full dimming potential. The system can dim continuously from full output to a minimum of 25% of full power. A careful examination of correlation between interior illuminance and electric lighting power consumption in 14 locations across the third floor reveals that dimming to low electric light levels occurred on only four circuits. The other circuits exhibit either some dimming at higher daylight levels, or no dimming at all. Figure 3 gives a typical example, where the scatter plot of lighting power versus illuminance is clearly not consistent with design objectives. Ideal system performance would show a reduction in electric power consumption while illuminance remains relatively constant at the 350-lux target. The illuminance level should increase only when the electric lighting system is fully dimmed. Though the architectural elements and dimming ballasts perform well, the lighting-control system responds poorly to available daylight. Fortunately, of the three components, the control system is the easiest to correct.

POTENTIAL IMPROVEMENT IN CONTROL-SYSTEM RESPONSE

To evaluate the benefit of improved control system performance, the potential for dimming of the electric lighting system was evaluated using data collected during weekends when the building was unoccupied and no electrical lighting component was used. Calculations for potential dimming on the third floor were based on nine days of 15-minute average readings from 8AM to 6PM. Illuminance readings for 24 locations across the building section were sorted into bins with 70-lux increments. The number of occurrences in each bin was multiplied by the lighting power percentage required to raise that bin to the target illumination level. Finally a summation of power required by each data location was weighted by the cross-sectional area represented by that location.

The dimming potential calculated by this process is summarized in Figure 4 for each illuminance sensor location across the third floor. The calculations indicate that the potential for dimming during summer occupied periods on the third-floor south side is 44% of full power, but actual measured consumption is 75%. On the third-floor north side the potential for dimming during occupied periods is 30% of full power while the actual average power consumption during occupied periods is 50%.

The poor performance of the control system can be linked to improper placement and calibration of control sensors. In this open-loop scheme, the control sensors measure available daylight transmitted through the view glazing below the interior light shelf. On the south side the view glazing has 17% transmittance, so the sensor sees a relatively dark region. The north side's glazing, with 41% transmittance, provides a stronger relationship between the control sensors and available daylight. In the atrium zones, the sensors are in the ceiling 2 meters from the atrium edge and see a more representative

illumination level. On the whole, the exterior-zone sensors are in poor locations to assess potential daylight, particularly for the beam component of daylight on the south side. This situation can be corrected by simply relocating the control sensors.

CONCLUSIONS

The detailed data collected in this daylighted building have yielded specific insights regarding performance of the daylighting components. The architectural features of the building are providing daylight as intended by its designer. The fluorescent dimming system, with proper control, can effectively manipulate the electric lighting power. The differentiation of task and ambient lighting systems has been an effective energy-conserving strategy that is appropriate for the daylight admitted into the building. The electric lighting control system has not been effective in capturing the energy savings inherent in the daylighting features. Techniques such as direct readout of the lighting levels and percentage of dimming are needed to give the operating personnel feedback as to how well the dimming system is working. In this case considerable additional electrical energy savings and peak electrical demand reduction can be generated by modification and adjustment of the existing lighting control system at minimal additional cost.

ACKNOWLEDGMENTS

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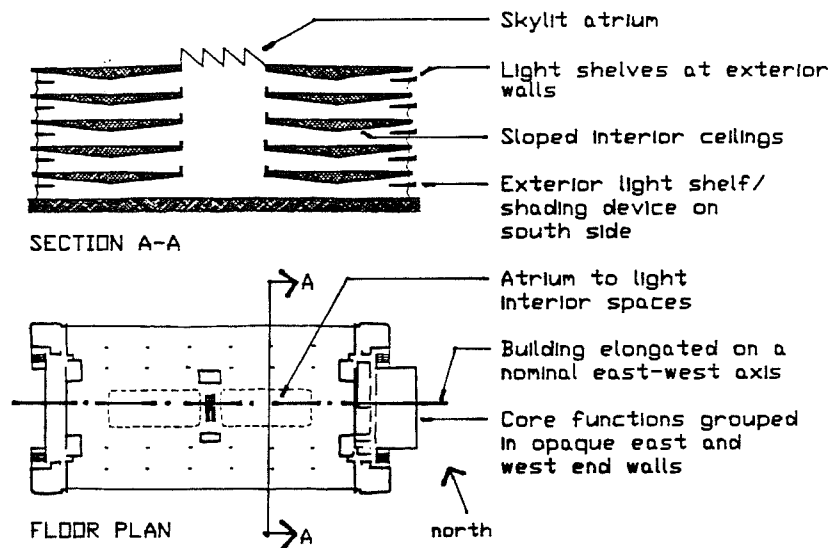


Figure 1. Diagram of building scheme.

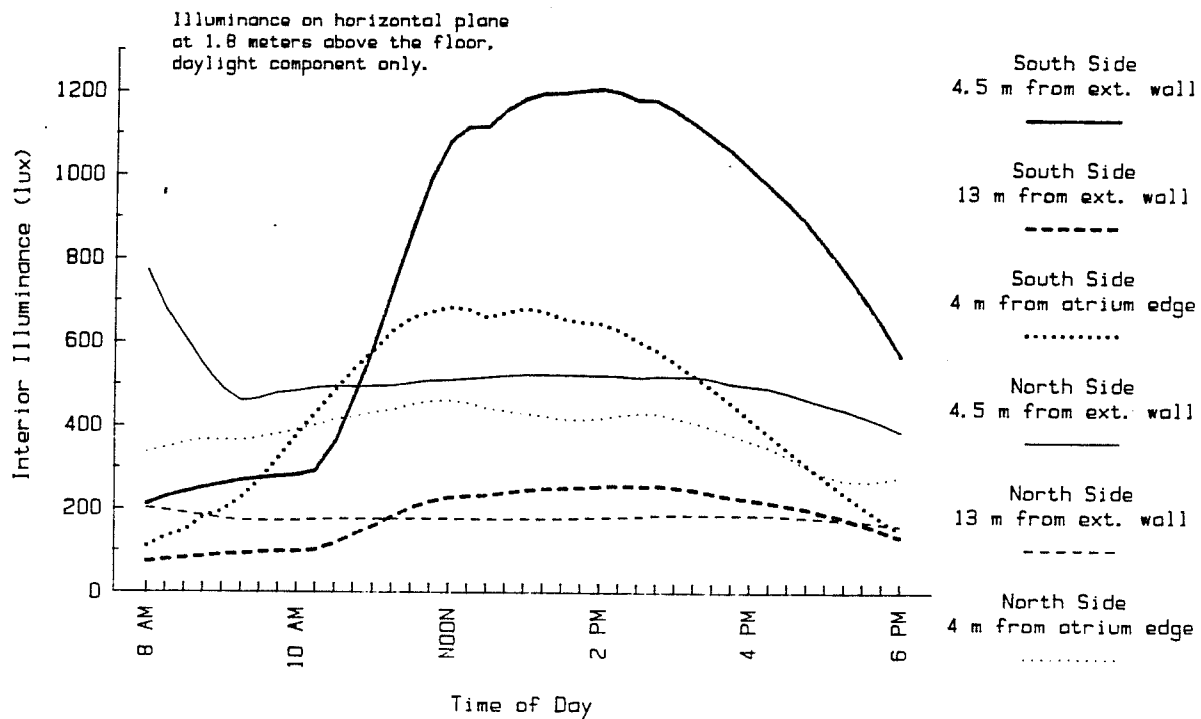


Figure 2. Interior illuminance values for a typical clear summer day.

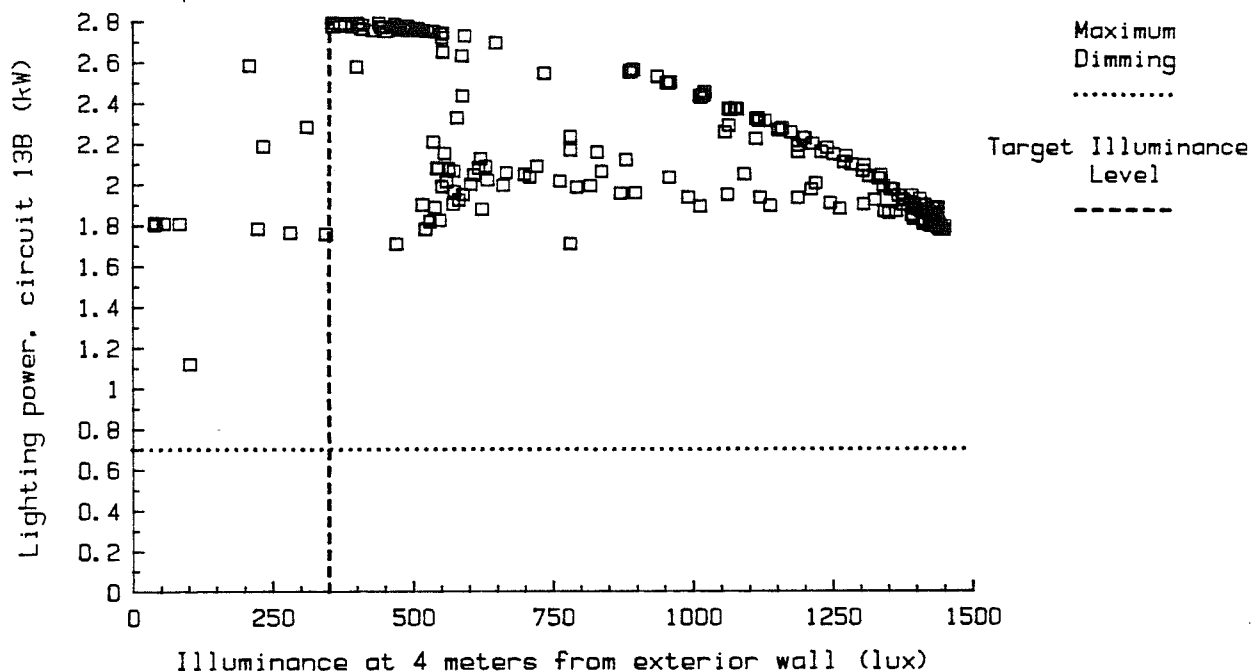


Figure 3. Electric lighting power vs. interior illuminance for a representative location in the south exterior zone (summer conditions).

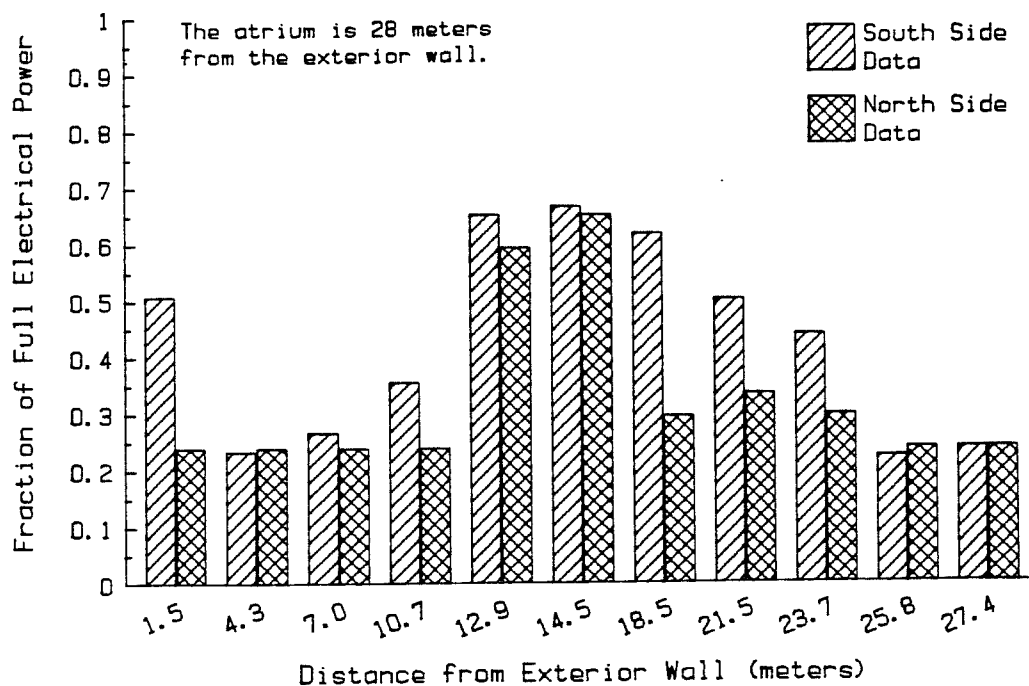


Figure 4. Dimming potential for the third floor shown as the fraction of full electrical lighting power required to achieve the target illuminance level (350 lux) for daytime occupied periods.